A COMPARISON OF PRECISION REGISTRATION PROCEDURES

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THESIS

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ABSTRACT

This thesis is addressed to the problem of selecting a precision registration procedure for the Field Artillery. The author hypothesized that, in view of recently procured automatic data processing equipment, the current procedure is neither the most accurate nor the most economical procedure possible. An alternate procedure was designed and compared with the current procedure through the use of a computer simulation model. Data from the simulation was analyzed and conclusions were drawn regarding the relative accuracy and economy of the two procedures.

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I. INTRODUCTION, SCOPE, AND OUTLINE

This thesis is addressed to the problem of selecting a precision registration procedure for the Field Artillery. It was hypothesized that, in view of newly developed data processing capabilities, the precision registration procedure currently in use is neither the most accurate nor the most economical procedure possible. An alternative procedure was developed to investigate this hypothesis. Computer simulation was employed to model the two procedures, generate data on each, and compare their relative economy and accuracy. It was not the author's intention to develop an optimal precision registration technique, but rather to compare the current procedure with one which uses the capabilities of automatic data processing to a greater extent.

Chapter II provides background information on the current precision registration procedure. The purpose of conducting registrations and the evolution of the current procedure are discussed along with the characteristics and requirements of that procedure. The reader who is familiar with these subjects may wish to omit Chapter II. On the other hand, the reader who has little knowledge of artillery may find it helpful in understanding Chapter II to refer to the Dictionary of United States Military Terms for Joint Usage [Ref. 9].

The alternate procedure, as modeled, is described in Chapter III. Suggestions for improving on the alternate procedure are contained in

Chapter VII along with the conclusions on the thesis. The experimental procedure, simulation model, and results are discussed in Chapters IV, V, and VI, respectively. A copy of the computer program used in the simulation model is included as Appendix A.

II. DEVELOPMENT OF CURRENT PRECISION REGISTRATION PROCEDURE

A. THE PURPOSE AND HISTORICAL DEVELOPMENT OF REGISTRATION

Field Manual 6-40 [Ref. 1], the manual which forms the basis of gunnery procedures employed by the United States Army and Marine Corps, describes the purpose of artillery registrations: "The purpose of a registration is to determine the firing data that will place the mean burst location of rounds fired with that data at a point of known location. Registration data is used to determine corrections which, when applied, will compensate for the cummulative errors contained in survey, the firing chart, material, and non-standard atmospheric conditions." If the cited conditions of material and weather were standard and no cummulative errors in survey and the firing chart were made, then firing a cannon at the elevation and deflection shown in the firing table would cause the projectile to strike at the exact range and deflection desired.[1] However, standard conditions of both material and weather are very rarely realized. The combined effects of the non-standard conditions causes rounds to fall over or short (range errors) and right or left (deflection errors) of the desired point of impact. If time fuze is employed there is

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[1] Artillery weapons may be howitzers or guns. The general term for both, which shall be used throughout this paper, is cannon or piece.

an additional error in height of burst. The amount of these errors can be estimated by registration and appropriate corrections made.[2]

Artillery registration was not a problem when the cannoneers could see their targets. "The first shot is for the Devil," ran a gunner's proverb, "the second for God, and only the third for the King." Veteran gun captains tried to ensure their first round would fall short so they could observe it, elevated for the second, and hoped to hit the target only with the third.[3] Until weapons were developed that could fire beyond the sight of their crews, they were fired much like hand guns; by "direct lay" (aiming at a visible target). Near the end of the nineteenth century, the increased range of cannon required the development of indirect laying techniques. The sight of one cannon in the battery, the base piece, was laid on some visible marker such as a stake or steeple. Then the angle between the marker and the unseen target was set off on the sight dial. The base piece was fired and adjusted in accordance with an observer's sensings. Appropriate corrections were then applied to the base piece and all other cannon in the battery. This

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[2] Errors in range and deflection are always estimated by registration. Time fuze may not be available obviating the necessity for computing height of burst errors. This paper will not consider registration with time fuze.

[3] Downey, F., The Sound of the Guns: The Story of American Artillery, p. 13, McKay, 1956.

technique allowed the artillerymen to fire from concealed positions on unseen targets. It was also the basis from which evolved the current precision registration procedure.[4]

The accuracy of artillery improved with the development of better sighting devices, cannon, and other equipment. In general, as new material became available, procedures were developed to take advantage of its potential. The present registration procedure was adopted more than twenty years ago concurrently with the target grid, a fire direction device. The suitability of the technique was not subjected to a theoretical analysis, but was based on empirical data input from a large number of registrations. Unfortunately, these data are no longer available.[5] The historical development of the American Artillery is documented by Downey [Ref. 2].

In recent years the application of automatic data processing (ADP) in the solution of fire direction problems has provided the Artillery another opportunity to expand its capabilities. The first artillery ADP system was FADAC. FADAC computed the solution of a limited number of fire direction and survey problems. In 1968, the Army contracted Litton Industries to develop an advanced automatic fire direction system,

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[4] Ibid, p. 179.

[5] Dewhurst, S. T., Letter, Subject: Request for Information, 13 June 1969.

TACFIRE. TACFIRE has a far greater capability than FADAC, performing functions in support of all the missions of the Artillery. A non-technical description of the TACFIRE System has been published by Litton [Ref. 3].

In its software specifications for TACFIRE, the Army instructed Litton to program the current registration procedure into the system. TACFIRE should enable the fire direction personnel to conduct the registration more quickly and with freedom from human arithmetic errors. However, this use of TACFIRE will <u>not</u> improve upon the inherent inaccuracy or ammunition costs of the procedure.

B. THE CURRENT REGISTRATION PROCEDURE

Relative to the more common types of fire missions, the precision registration involves unique procedures in fire direction, extraordinary accuracy on the part of the cannoneers, and special requirements in survey.

Only one gun, the battery base piece, is used to conduct the precision registration. During the conduct of the registration, the cannoneers check the orientation of their weapon after each round. The Forward Observer, following a specified procedure, adjusts or senses the rounds relative to a registration point. The registration point is a specially selected target which is readily identifiable by the Observer, located near the center of the target area, and permanent or semi-permanent in nature. Both the registration point and the base piece must be located by survey.

The fire direction procedure employed in the precision registration is based on an assumed dispersion pattern and the parameters connected with that pattern. It has been established by experimentation that rounds fired from an artillery weapon, at a fixed elevation and deflection, fall in accordance with a bivariate normal pattern of bursts. The standard deviation of the range dispersion is used to determine a factor known as a fork. One fork is the change in elevation, measured in mils, necessary to move the mean point of impact four range probable errors. One probable error is .6745 standard deviations. Therefore, a shift of four probable errors is approximately 2.7 standard deviations, and virtually all rounds fired at a single elevation setting will fall within one fork of the mean point of impact. Probable errors in deflection are relatively small, so shifts in deflection are based more directly on the mil relation. The factor used in computing deflection shifts is known as S. Ths factor S is determined from the range to the registration point, and the relative positions of the weapon, target, and observer. The value of the fork is found in firing tables, and S is tabulated on the registration recording form. A complete discussion of the analytical basis of the current precision registration procedure may be found in Section IV, Chapter 2, Field Manual 6-40 [Ref. 1].

The current precision registration procedure employs two phases; adjustment and fire for effect. During the adjustment phase, the Forward Observer makes shifts in range so that some rounds fall over and others fall short of (bracket) the registration point. In deflection he attempts to shift the rounds onto the line from his position through the registration point (observer-target line). After adjusting the bursts to within approximately 100 meters of the registration point (two hundred meters if range probable error exceeds 38 meters); the mission enters the fire for effect phase. During fire for effect, the fire is adjusted by the Fire Direction Center (FDC) based on the observer's sensings (over, short, right, left and doubtful). These sensings are converted from the observer-target line to the gun-target line and elevation and deflection changes are made based on the values of fork and S. Shifts of one S in deflection are made until the correct deflection is determined. The deflection is considered correct when a target hit is obtained, or a two mil deflection bracket is split, or deflection spottings of right and left are obtained from the same deflection setting, or deflection spottings of right and left are obtained from deflection settings one mil apart. Elevation changes in forks or half-forks are made until six definite range sensings are obtained with at least one round over and short of the registration point. Due to the procedure followed, the six rounds considered are fired in two groups of three at two elevation settings, 1/2 fork apart. The change in elevation required to move the mean point of impact of the six rounds onto the target is computed by using a "preponderance formula":

$$\text{Elevation Change} = \frac{\text{Difference in overs and shorts X Fork}}{\text{2 X number of rounds considered}}$$

Thus an adjusted elevation and deflection are determined which estimate the settings required such that the center of impact of rounds fired at these settings is coincident with the registration point. The complete procedure for the conduct of precision registrations is found in Section II, Chapter 19, Field Manual 6-40 [Ref. 1].[6]

With the current precision registration procedure, it is assumed that the six rounds used to compute the adjusted elevation are all derived from the same normal distribution. Since these rounds are fixed at two quadrant elevations, two probable errors apart, their distribution is actually bimodal with a larger variance than that of the assumed distribution. The preponderance formula used to determine the elevation change to move the mean point if impact over the registration point approximates computing the change from probability tables. Reference 1 states that these approximations and assumptions are made for the sake of simplicity and because the small number of rounds considered does not warrant striving for extra precision.

In addition to the mathematical assumptions involved in the current procedure, there is an implied assumption about the capabilities of the fire direction system itself. In an effort to maintain simplicity, not all of the available information is used. During the adjustment phase the

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[6] Although both elevation and deflection corrections are computed on each round in fire for effect, adjusted deflection is usually determined before adjusted elevation, due to the relatively small probable error in deflection.

observer makes shifts large enough to assure bracketing the registration point. This phase of the procedure eventually locates the registration point within approximately 100 meters in range. In deflection, on the other hand, the observer strives to shift the rounds exactly to the observer-target line. Thus more information about deflection is transmitted than about range. During the fire for effect phase the observer only reports, if possible, the quadrant in which the round has fallen. Unless a gross error is suspected, he never gives his estimate of the distance from the burst to the registration. Thus, it is implied that the fire direction system is capable of handling only a part of the information available to the Forward Observer.

Unused information leads to inefficiency, a cost of employing the procedure. The Gunnery Department of the United States Artillery and Missile School had indicated that until 1966 no attempt was made to determine the accuracy of the precision registration procedure [Ref. 5]. At that time a limited study of accuracy, The Theoretical Study of Registration Procedures [Ref. 6], was conducted. It was found that mean miss distance increased linearly with probable error in range. Other results of this Study are discussed in a later chapter.

The ammunition used is an obvious cost of registering. Collateral with the ammunition cost is the cost in time and tactical surprise. If the current procedure is followed exactly, the number of projectiles required is nine.[7] Due to "doubtful" sensings, failure to achieve appropriate brackets, and other factors; the number of rounds required in practice to complete a precision registration is usually in the eleven to thirteen range.[8]

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[7]Under some combat situations ad hoc methods of registration, using fewer rounds, are often adopted for the sake of time and economy.

[8]Historical data on ammunition expended for registration is not available. The figures cited above are estimates based on the experience of the author.

III. AN ALTERNATIVE PROCEDURE

A. BACKGROUND

While designing the software components for the TACFIRE System, operations research analysts at Litton Industries considered proposing to the Army an alternative procedure for conducting precision registration.[9] Due to lack of time, the proposal was not developed for submission. The alternative procedure described herein is based on ideas originating at Litton [Ref. 4]. The procedure described in what follows is not intended for consideration for adoption. In fact, it may be shown that this procedure can readily be improved. This procedure was developed as a method of demonstrating the existence of <u>a</u> procedure that is an improvement over the one in current use.

B. THE PROCEDURE

If TACFIRE is available, the technical requirements for the alternate procedure are the same as those of the current procedure. The actions of all personnel, except the Forward Observer, are the same. The Forward Observer neither brackets the registration point, nor enters a fire for effect phase. Instead, he attempts to bring each round to the registration point throughout the mission. The observer, in attempting to move the burst onto the registration point, gives an approximate location of the

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[9] Software pertains to the programs associated with a computer as opposed to hardware such as the computer itself.

burst. After each of the observer's reports the computer updates the pattern of bursts to include the most recent round, computes the center of impact in range and deflection and determines an estimate of the shift required to move that center of impact onto the registration point. This procedure is repeated for a predetermined number of rounds, the final shift is applied to the elevation and deflection settings used on the final round, and an adjusted elevation and deflection are thereby determined.

The alternative procedure makes successive approximations of the mean of the pattern of bursts by updating the pattern to include each round as it is fired and then computing the mean point, in range and deflections, of all rounds fired. It is assumed that the updated rounds fired in this procedure form a bivariate normal distribution about the center of impact. Therefore, firing more rounds is analogous to taking more observations from a bivariate normal distribution. The procedure is equivalent to using the sample to estimate the mean of that distribution. Deflection and range errors along the gun-target line are assumed independent and with an angle T of zero the same assumption applies to the observer-target line. Therefore, the off-diagonal elements of the covariance matrix of the distribution are assumed to be zero. The diagonal elements of the matrix should be somewhat larger than the range and deflection variances due to the inherent observer errors.

Relative to the current procedure, the alternate assumes a higher capability in information processing on the part of the fire direction system, as augmented by TACFIRE. It also assumes that the observer can report range and deflection corrections with "reasonable" accuracy. (The simulation model was used to perform a modest sensitivity analysis on the observer's errors. The results are discussed in later chapters).

As in the current procedure, there are costs in accuracy and ammunition associated with the alternate procedure. Determining the relative levels of these costs was possible using a computer simulation model of the two procedures.

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Some collateral measure of effectiveness considered in this experiment were consistency of performance and time to complete the registration. Tactical surprise should also be considered, but it can be measured in terms of time to complete the registration which, in turn, should be linearly related to the number of rounds fired. Thus, time and tactical surprise are measured concurrently with economy, in terms of the average number of rounds required to complete a precision registration.

Consistency of performance, on the other hand, cannot be measured in terms of one of the primary measures of effectiveness. Consistency is defined here in terms of the variance of the radial miss distances observed in 1000 replications of a precision registration procedure using one weapon at one range. Procedures resulting in small variance are considered to be more consistent than those with larger variances.

C. ENVIRONMENT

The weapon characteristics modeled in the experiment were those of the 155 millimeter howitzer. These characteristics were taken from Firing Table 155-Q-3 [Ref. 7]. Ranges at which the experiment was conducted were 4000, 8000, and 12000 meters. These ranges were selected in order to take into account possible differences in firing characteristics at short, medium and long ranges.

Angle T, the angle between the gun-target line and the observer-target line, was assumed to be zero. Selection of a zero Angle T has no effect on the performance of the alternate procedure, but does simplify the computations within the model. For the current registration procedure an Angle T of zero tends to yield better results than would otherwise be expected, due to the elimination of doubtful FDC sensings. Therefore, selection of an Angle T of zero should tend to enhance the simulated performance of the current procedure as compared with that of the alternate procedure.

As modeled in the simulation, the Forward Observer makes random errors of up to 50% in estimating the distance from the burst to the registration point. For example, a round which burst 100 meters over would be sensed, with a uniform probability distribution, from 150 to 50 meters over. This error was chosen because it appeared to the author a rather low (conservative) estimation of the ability of the Forward Observer. The effects of various observer error assumptions on the results of precision registration are discussed later.

All other parametric values pertinent to the model, namely probable errors in range and deflection, and the values of Fork and S, were taken from the appropriate firing tables. Elevation and charge used at the ranges modeled were those resulting in minimum range probable error. No FDC errors are modeled in the simulation, an appropriate assumption since both procedures were simulated as being conducted by TACFIRE.

D. STATEMENT OF HYPOTHESES

In general terms, the experiment sought to test the validity of the following propositions:

1. The accuracy of the alternate precision registration procedure is greater than that of the current procedure for the same ammunition cost.

2. The economy of the alternate precision registration procedure, and hence its timeliness and level of tactical surprise, is greater than that of the current procedure while achieving the same accuracy.

3. The alternate precision registration procedure yields more consistent results than the current procedure.

These propositions were examined by comparing the results of simulated registration missions and by testing the following statistical hypotheses:

1. H: The radial miss distance which results from expending six rounds in the conduct of a precision registration following the alternate technique is the same as that which results from conducting the precision registration while following the current technique.

HA: The radial miss distance which results from expending six rounds in the conduct of a precision registration following the alternate technique is less than that which results from conducting the precision registration while following the current technique.

2. H: The radial miss distance which results from expending ten rounds in the conduct of a precision registration following the alternate technique is the same as that which results from conducting the precision registration while following the current technique.

HA: The radial miss distance which results from expending ten rounds in the conduct of a precision registration following the alternate technique is less than that which results from conducting the precision registration while following the current technique.

The values six and ten were chosen because the current procedure requires the use of at least six rounds in the fire for effect phase alone and, as modeled, it required more than ten rounds, on the average, in registration.

The computer simulation model is described in the following chapter. Results from the model include the average (over 1000 registrations) radial miss distance achieved by the current procedure and by the alternate procedure using six and ten rounds. The variance in the resulting miss distances was also computed. Results were recorded at each of the three test ranges; 4000, 8000, and 12000 meters. The two statistical hypotheses were tested at each range using a one-sided T-Test for the means of two populations with different variances. The method of computing T-statistics using populations with different variances was taken from Ostle [Ref. 12].

V. TESTING AND OPERATING THE MODEL

A. DESCRIPTION OF THE MODEL

The computer simulation model used in the conduct of this experiment was written in FORTRAN IV language and run on an IBM 360-67 computer.

The model consists of a main program, three subroutine subprograms, and two function subprograms. Two subroutine subprograms model the current and alternate precision registration procedures. The third subroutine subprogram computes the T-statistics for analysis of results. One of the function subprograms generates normal and uniform random deviates, and the other generates forward observer errors.

The main program controls the model by establishing the parameters to be used throughout, maintaining records of results, and counting the missions completed. One thousand precision registrations are simulated using each of three procedures at three test ranges. First: a range is selected along with the associated probable error values. The location of the first burst in each mission is established in the main program, and is uniformly distributed over a rectangle 400 meters by 200 meters centered on the registration point. The location is determined by calling the random number generator to provide a random number uniformly distributed over [0, 1].[10] This number is multiplied by 200 to establish a miss distance in range. The generator is used again to determine a sign for this value of miss distance. The same method determines the location of the round in deflection except that a multiplier of 100 vice 200 is used. Then the subroutine subprogram that models the current registration procedure is called. Radial miss distance, and the number of rounds required to conduct the registration using this procedure are returned to the main program and added to records of running totals. The process begins again with another first round and continues for 1000 repetitions. After the last registration is completed the average number of rounds used, average radial miss distance, and the standard deviation in miss distance are computed. The mission counter and running totals are then set to zero and the process is begun again at the same range, but using the alternate procedure firing six rounds. After 1000 missions, average values are computed and the T-Test subroutine called to compare the average radial miss distances of the two procedures. For a third time the appropriate values are set to zero and the process restarted; this time using the alternate procedure firing ten rounds. The results from this procedure are also compared with those from the current procedure using a T-Test. The process of conducting 1000 simulated registrations using each procedure is repeated at each of the three test ranges.

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[10] A subprogram is "called" by a main program or other subprogram. When the called subprogram has completed its computations the results are "returned" to the calling program.

The function subprogram which generates uniform and normal random deviates is based on Subroutines GAUSS and GRN from the IBM Scientific Subroutine Package [Ref. 8]. The uniform deviates are used in determining first round locations, the percentage of miss distance to be used as an observer error, and the sign of value (+ or -) as required. The normal deviates are used in determining the location of subsequent rounds, both in range and deflection. Normal deviates, X, from a distribution with a mean of zero, and a standard deviation of one can be transformed to a normal deviate, Y, from a distribution with mean, MU, and standard deviation, SIGMA by the formula:

Y = (X) (SIGMA) + MU

In the model, range distribution about a point, RANGE, is simulated by transforming a normal random deviate from the generator to a distribution with mean, RANGE, and range probable error, PER by the formula:

Y = (RAN (0)) PER/.6745 + RANGE

A similar computation is made to determine the burst location in deflection.

The function subprogram which generates the observer error calls for a uniform random deviate from the random number generator and multiplies it by .50. A sign for the resulting percentage is determined by again calling for a uniformly distributed random deviate, and applying a plus sign if the number returned is greater than .5, and a minus sign otherwise. The miss distance of the round is then multiplied by the signed percentage. The resulting distance is added algebraically to the miss distance, thus simulating the selection of a sensing by an observer whose errors in judging miss distances are uniformly distributed over [-50%, +50%] of the miss distance. Sensings for range and deflection are computed separately.

The subroutine subprogram that simulates the current registration procedure maintains two parallel sets of data; one based on the location of bursts as actually generated, the other based on the location of bursts as estimated by the procedure. A range shift of 200 meters and a deflection shift onto the observer-target line are made after the first round location has been determined by the observer. As simulated, the observer never errs in following the bracketing algorithm of the current procedure. However, his efforts to shift in deflection are subject to the observer error function of up to 50% of the true miss distance. After taking into account the shifts called for by the observer, a new point of aim in range and deflection is computed and the next burst location determined. As stated previously, the subsequent bursts are located according to a bivariate normal distribution about the point of aim. This process is continued until a shift of 50 meters is made, ending the adjustment phase of the registration (100 meters, if range probable error exceeds 38 meters). During the fire for effect phase, range shifts of one fork are made until a bracket is established. Simultaneously, shifts of one S are made until a deflection bracket is established. The range bracket is split and three rounds are fired at the resulting range. Deflection brackets continue to be split until a half-S bracket is split, at which time deflection is correct by definition.[11] As in the adjustment phase, each simulated burst is distributed about the point of aim as a bivariate normal random deviate. The sensings, over or short, of all rounds are recorded and range shifts made in accordance with the procedure. When the six sensings, required by the procedure for determining adjusted elevation, are available, the mission is ended. A correction is determined using the "preponderance" formula, and the estimated location of the center of impact is computed. This estimated location is compared with the true center of impact, determined from the previously mentioned record of true burst locations. The radial distance from the estimated to the true center of impact is determined by computing the square root of the sums of the squares of the differences in range and deflection.

The model of the alternate procedure is similar to that of the current procedure in that the first round burst location is provided by the main program, and parallel data on true burst location, as well as that estimated by the procedure, are maintained. Burst location is determined by generating a random deviate with appropriate mean and variance. The observer's estimate, in range and deflection, of this location is simulated by calling the function subroutine that applies the 50% error to the observer sensing. After each observer estimate, a new mean is

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[11] "Target" and "Line" sensings occur with probability zero in the simulation. Therefore, splitting a half-S bracket is the only way to determine correct deflection.

computed. The shift required to place the new estimate of the mean over the registration point is applied to the location of all rounds. After the appropriate number of bursts, six or ten, have been simulated, a final center of impact is computed, and the appropriate shift applied. The resulting location is compared with the true center of impact and the difference returned to the main program.

The subroutine which computes T-statistics on the results of the simulated procedure was taken directly from the IBM Scientific Subroutine Package [Ref. 8]. The complete computer program listing used in this simulation is contained in Appendix A.

B. PRELIMINARY OPERATIONS OF THE MODEL

Prior to its comparison with the model of the alternate procedure, the model of the current procedure was tested for validity. The accuracy of the current procedure, as modeled, closely approximated that found in Ref. 6, The Theoretical Study of Registration Procedures. For the three values of probable error in range for which the experiment was conducted, the mean miss distances in range compared as follows:

PER	SIMULATION MODEL	STUDY [REF. 6]
16	11.82	11
31	23.25	20
42	29.35	28

As simulated, the current procedure required an average of 10.17 rounds to complete a registration. Since no doubtful sensings were possible due to the choice of Angle T as zero, this average seems, in the experience of the author, to be reasonable. The decision to test the alternate procedure at ten rounds as well as six was based on the average ammunition expenditure by the current procedure in these preliminary tests.

An observer error of up to 50% of the miss distance was programmed following sensitivity tests at the 25, 50, 75, and 100 percentage levels. This function applied to all range and deflection sensings in the alternate procedure, causing that procedure to be more sensitive to changes in the function than the current procedure. This is because, in the current procedure, the function applied only during the adjustment phase, and then only to deflection sensings. No change in the final results of the experiment occurs when observer errors are maintained at 75% or less. At the 100 percentage level, that is when the error can be as large as the miss distance, the alternate procedure becomes inefficient, because in some registrations the final estimated center of impact is further from the registration point than could have been estimated without the benefit of registration. A 50% level of observer error was chosen for the final tests of the model because it appeared to the author to be a conservative estimate of the ability of an average observer to measure miss distance in range, and seemed absurdly conservative in estimating his ability to measure miss distance in deflection.

Having established that results from the model of the current procedure closely approximated those indicated in Ref. 6, and having chosen the parametric values to be used, the final comparisons of the modeled procedures were begun. As described previously in this chapter, each run of the simulation program involved conducting 1000 registrations using each procedure at each of three test ranges. T-tests on the resulting data were performed, the T-statistics and their associated degrees of freedom were included in the output of the model. Total computer time required to conduct the simulation and analysis was 160 seconds.

VI. RESULTS

A. TABULATED RESULTS

The following tables contain the results of the simulation. "C" refers to the current procedure, "A-6" refers to the alternate with six rounds fired, and "A-10" refers to the alternate with ten rounds fired.

Range: 4000 PER: 16.00 PED: 1.00

	Rounds Used	Average Miss Distance	Standard Deviation in Miss Distance	T Statistics	Degrees of Freedom
C	10.18	12.33	8.97	-	-
A-6	6	7.85	6.08	-13.1	1758
A-10	10	5.06	3.72	-23.7	1333

Range: 8000 PER: 31.00 PED: 2.00

	Rounds Used	Average Miss Distance	Standard Deviation in Miss Distance	T Statistics	Degrees of Freedom
C	10.17	24.02	17.30	-	-
A-6	6	8.59	6.13	-26.6	1246
A-10	10	5.66	3.86	-32.7	1099

Range: 12000 PER: 42.00 PED: 4.00

	Rounds Used	Average Miss Distance	Standard Deviation in Miss Distance	T Statistics	Degrees of Freedom
C	10.16	31.45	22.27	-	-
A-6	6	9.45	6.87	-29.8	1188
A-10	10	6.59	4.55	-34.6	1082

B. RESULTS OF HYPOTHESIS TESTS

Based on the T-statistics in the tables above, both statistical hypotheses were rejected at the $\alpha = .0005$ level.

C. DISCUSSION OF RESULTS

Overall, procedure A-10 was nearly four times more accurate than procedure C for approximately the same ammunition cost. For an average of 4.7 rounds less per registration, procedure A-6 was 2.6 times as accurate as procedure C. The accuracy difference was the greatest at the longest range where average miss distance differed by factors of 3.3 and 4.8 for A-6 and A-10 respectively. The accuracy of A-6 and A-10 was more consistent than C. The accuracy of the latter procedure was very sensitive to changes in probable error. Miss distance using procedure C increased by 155% as PER increased 162%. The same change in PER caused only a 20% decrease in the accuracy of A-6 and 30% for A-10. The differences in miss distance between C and A-6 and C and A-10 were both found to be highly significant ($\alpha = .0005$). Similar results were obtained in comparing the standard deviations of the miss distance. The alternate procedures both displayed standard deviations which were far lower and more consistent than that of the current procedure, C.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The results from the computer simulation model clearly indicate the availability of a precision registration procedure superior to that in current use. The alternate procedure tested in the simulation, although not of optimal design, proved significantly more accurate and economical than the current procedure. In addition, the alternate procedure was far more consistent throughout the spectrum of ranges than that in current use.

The procurement of TACFIRE provides the potential for a greatly improved precision registration procedure. The current procedure was developed for use by a highly constrained fire direction system. It is illogical and wasteful to program the same procedure for use in a system that eliminates or greatly reduces the old constraints.

The development of new target acquisition devices for use by the Forward Observer will render the current procedure even more obsolete. No amount of improved accuracy on the part of an observer can improve the accuracy or economy of the current procedure.[12] On the other hand, any such improvement would enhance the performance of a procedure similar to the alternate presented herein.

---

[12] This statement is made in the context of this thesis, in that the Forward Observer makes no sensing or procedural errors. Improved target acquisition devices would be helpful in eliminating such errors using any procedure.

B. AREAS FOR FURTHER RESEARCH

It appears that a study to determine the accuracy of a Forward Observer in sensing miss distances has never been conducted. In 1968 the Combat Development Experimentation Command conducted an experiment involving forward observers [Ref. 11], but the scope of the experiment did not include the determination of miss distance. Such information would prove very useful in future comparisons of registration procedure in that it would reduce the subjectivity involved in determining the observer error function.

As was demonstrated in the simulation model, procedures such as the modeled alternate do not require the firing of a fixed number of rounds. An increase in the number of rounds fired leads to greater confidence that the estimated center of impact is within a desired tolerance distance about the true mean. This feature allows the Fire Direction Officer some flexibility in determining the proper balance of accuracy, economy, and time. Once such a procedure was adopted, tables of confidence intervals, based on range and ammunition expended, could be developed. The result would be control and flexibility at a level never before available to those responsible for technical fire direction.

A more technical area where further research should prove fruitful would be in determining the proper statistical weights to assign rounds fired in a procedure such as the alternate. Obviously, shifts made on bursts near the target should be more accurate, and therefore "count" for more, than very large shifts. Any adopted weighting scheme could be applied by the computer and could, therefore, increase accuracy without any added effort on the part of the fire direction personnel.

C. RECOMMENDATIONS

It is recommended that the Army investigate possible alternatives to the precision registration procedure to be programmed into TACFIRE. A new procedure, taking greater advantage of the capabilities of TACFIRE and other new equipment being procured by the Army, should be developed.

APPENDIX A

A COMPARISON OF SIMULATED PRECISION REGISTRATION PROCEDURES

```
C
C     THE MAIN PROGRAM CONTROLS THE SIMULATION BY DESCRIBING
C  THE PARAMETERS TO BE USED THROUGHOUT, MAINTAINING A
C  COUNT OF MISSIONS FIRED, AND PERFORMING SOME GENERAL
C  CALCULATIONS.
C
      REAL MISDIS,MISS
      INTEGER Z,Z2,RDDIFF,DIFF
      COMMON RN,PER,FIRST,IADD,MISDIS,DISP,Z,AWAY,STDDEV,Z2,
     AAWAY2,STDV2,DIST,FERST,PED,STDDV,NROUND
      DIMENSION MISS(1000),STAND(1000)
C
C     INITIALIZE THE RANDOM NUMBER GENERATOR.
C
      START=RAN(-351)
      ICASE=-1
      SUM=0
      SUM2=0
      DIST=0
      TOTAL=0
      TOTAL2=0
      DIFF=0
      SQMISS=0
    1 IF(ICASE)2,3,4
C
C     DETERMINE PARAMETERS ASSOCIATED WITH TEST RANGES.
C
    2 RN=4000
      PER=16.00
      PED=1
      GO TO 5
    3 RN=8000
      PER=31.00
      PED=2
      GO TO 5
    4 RN=12000
      PER=42.00
      PED=4
    5 WRITE(6,100)RN,PER,PED
      ITEM=-1
C
C     START THE MISSION COUNTER
C
   13 ICOUNT=0
   55 ICOUNT=ICOUNT+1
C
C     ESTABLISH THE LOCATION OF THE FIRST ROUND FIRED IN THE
C  MISSION.  FIRST REFERS TO RANGE, FERST TO DEFLECTION.
C
      FIRST=RAN(1)*200
      IF(RAN(1).GT..5) GO TO 6
```

```
      FIRST=-FIRST
    6 FERST=RAN(1)*100
      IF(RAN(1).GT..5)GO TO 7
      FERST=-FERST
    7 IF(ITEM)8,9,10
C
C     CALL THE MODEL OF THE CURRENT REGISTRATION PROCEDURE.
C
    8 CALL OLD
      STAND(ICOUNT)=MISDIS
      GO TO 11
C
C     CALL THE MODEL OF THE ALTERNATE REGISTRATION PROCEDURE
C   FIRST WITH 6 ROUNDS FIRED, SECOND WITH 10 ROUNDS FIRED.
C
    9 NROUND=6
      CALL NEW
      MISS(ICOUNT)=MISDIS
      GO TO 11
   10 NROUND=10
      CALL NEW
C
C     MAINTAIN RUNNING TOTALS FOR EACH PROCEDURE.
C
      MISS(ICOUNT)=MISDIS
   11 SUM=SUM+IADD
      SUM2=SUM2+MISDIS
      SQMISS=SQMISS+MISDIS**2
      TOTAL=TOTAL+DISP
      TOTAL2=TOTAL2+STDDV
      IF(ICOUNT.LT.1000)GO TO 55
      ITEM=ITEM+1
C
C     AFTER 1000 MISSIONS COMPUTE THE AVERAGES AND STANDARD
C   DEVIATIONS, ZERO THE RUNNING TOTALS, AND PRINT THE RESULT
C
      AV1=SUM/ICOUNT
      AV2=SUM2/ICOUNT
      AV3=TOTAL/ICOUNT
      AV4=TOTAL2/ICOUNT
      SIGMA=SQRT(SQMISS/ICOUNT-AV2**2)
      SQMISS=0
      SUM=0
      SUM2=0
      TOTAL=0
      TOTAL2=0
      WRITE(6,105)AV1,AV2,AV3,AV4
      WRITE(6,107)SIGMA
      IF(ITEM.EQ.0)GO TO 12
C
C     IF AN ALTERNATE PROCEDURE HAS JUST BEEN FIRED 1000
C   TIMES, CALL THE T-TEST FOR COMPARISON WITH STANDARD SET
C   BY CURRENT PROCEDURE.
C
      CALL TTEST(STAND,ICOUNT,MISS,ICOUNT,3,NDF,ANS)
      WRITE(6,109) NDF,ANS
   12 IF (ITEM.LT.2)GO TO 13
      ICASE=ICASE+1
      IF (ICASE.LE.1) GO TO 1
  100 FORMAT(1H1,18X,'RANGE:',F6.0,' METERS PROBABLE ERROR I
     AN RANGE:',F6.2, ' PROBABLE ERROR IN DEFLECTION:',F6.2)
  105 FORMAT(//T7,' AVG ROUNDS USED:',F6.2,' AVG MISS DISTAN
     ACE:',F8.2,/,T7,' AVG STANDARD DEVIATION IN RANGE:',F8.
     B2,' AVG STANDARD DEVIATION IN DEFLECTION:',F8.2)
  107 FORMAT(/,T7,' STANDARD DEVIATION OF MISS DISTANCE:',F8
     A.2)
  109 FORMAT(/,T7,' NUMBER OF DEGREES OF FREEDOM FOR T-TEST:
     A',I6,//,T7,' T STATISTIC:',F10.4)
      STOP
      END
```

```
C
C     THIS SUBROUTINE GENERATES UNIFORM OR NORMAL RANDOM
C   DEVIATES OVER(0,1).
C

      FUNCTION RAN(J)
C     FOR J LT 0 SET INITIAL VALUE OF GENERATOR
C     FOR J EQUAL 0 GENERATE NORMAL (0,1) NUMBER
C     FOR J GT 0 GENERATE UNIFORM (0,1) NUMBER
      IF(J.GE.0) GO TO 10
      IX=1-2*J
      X=0
      GO TO 150
   10 IX=IX*65539
      IF(IX.LT.0)IX=IX+2147483647+1
      X=FLOAT(IX)*.4656613E-9
      IF(J.NE.0)GO TO 150
      DO 100 I=1,11
      IX=IX*65539
      IF(IX.LT.0)IX=IX+2147483647+1
  100 X=X+FLOAT(IX)*.4656613E-9
      X=X-6.0
  150 RAN=X
      RETURN
      END
```

```
C
C     THIS SUBROUTINE DETERMINES THE FORWARD OBSERVER ERROR
C   FUNCTION.  THIS ERROR IS ASSUMED TO BE UNIFORMLY DISTRI-
C   BUTED ABOUT ZERO AS 50% OF THE MISS DISTANCE.
C

      FUNCTION ERRFCN(X,Y)
      ERROR=RAN(1)*.5*ABS(Y)
      IF (RAN(1).GT..5)GO TO 1
      ERROR=-ERROR
    1 ERRFCN=Y+ERROR
      RETURN
      END
```

```
C
C     THIS SUBPROUTINE MODELS THE CURRENT PRECISION REGISTRA-
C  TION TECHNIQUE.
C

      SUBROUTINE OLD
      REAL MISDIS,IUSE
      INTEGER Z,Z2,RDIFF,SHORT,OVER
      LOGICAL LESS
      COMMON RN,PER,FIRST,IADD,MISDIS,DISP,Z,AWAY,STDDEV,Z2,
     AAWAY2,STDV2,DIST,FERST,PED,STDDV,NROUND
      DIMENSION ADJ(20),FFE(20),IUSE(10),WIDE(10),WIDFFE(10)
C
C     ZERO ALL ARRAYS
C
      DO 22 I=1,10
      IUSE(I)=0
      WIDE(I)=0
   22 WIDFFE(I)=0
      DO 23 I=1,20
      ADJ(I)=0
   23 FFE(I)=0
      I=0
      J=1
      K=0
      N=1
      OVER=0
      SHORT=0
C
C     THE FIRST ROUND IS TAKEN AS SENT FROM THE MAIN PROGRAM
C
      DEFLEC=FERST
      WIDE(1)=FERST
      RANGE=FIRST
      ADJ(1)=FIRST
C
C     IN ACCORDANCE WITH THE PROCEDURE, THE FIRST RANGE
C  SHIFT IS OF 200 METERS.  DEFLECTION SHIFTS ARE ONTO LINE.
C
      SHIFT=200
    1 CORECT=-ERRFCN(DIST,WIDE(J))
      DEFLEC=DEFLEC+CORECT
      IF(ADJ(J).LT.0.0) GO TO 2
      LESS=.FALSE.
      RANGE=RANGE-SHIFT
      GO TO 3
    2 LESS=.TRUE.
      RANGE=RANGE+SHIFT
C
C     WHEN THE SHIFT IN RANGE IS 50 METERS, FIRE FOR EFFECT
C  PHASE IS ENTERED.
C
    3 IF(SHIFT.EQ.50) GO TO 6
      IF(SHIFT.EQ.100.AND.PER.GT.38.0)GO TO 6
      J=J+1
C
C     BY USING THE SUBROUTINE"RAN",THE STRIKE OF ROUNDS IS
C  DETERMINED BY DISTRIBUTING THE FALL OF SHOT ABOUT THE
C  POINT OF AIM AS A BIVARIATE NORMAL DISTRIBUTION WITH
C  PARAMETERS BASED ON THE PROBABLE ERRORS.  THE N(0,1) RAN-
C  DOM DEVIATE RETURNED FROM "RAN" IS CONVERTED FOR USE BY
C  APPLYING THE FORMULA X=(NUMBER-MEAN)*STANDARD DEVIATION.
C
    4 ADJ(J)=(RAN(0))*PER/.6745+RANGE
      WIDE(J)=(RAN(0))*PED/.6745+DEFLEC
C
C     LOGICAL IF STATEMENTS AS THE ONE FOLLOWING ARE USED TO
C  DETERMINE THE RELATIVE SENSINGS OF THE ROUNDS.
C
      IF(SHIFT.NE.200)GO TO 5
```

```
      IF(ADJ(J).LT.0.0.AND.LESS.OR.ADJ(J).GT.0.0.AND..NOT.LE
     ASS) GO TO 1
C
C     HALVE THE SHIFT, REDUCING THE BRACKET.
C
    5 SHIFT=SHIFT/2
      GOTO 1
C
C     ENTERING FIRE FOR EFFECT.
C
    6 FFE(N)=(RAN(0))*PER/.6745+RANGE
    7 IF(FFE(N).LT.0.0) GO TO 8
      LESS=.FALSE.
      IUSE1=FFE(N)
C
C     IN FFE PHASE SHIFT ONE FORK ( FOUR PER ) UNTIL
C   AN OPPOSITE RANGE SENSING IS ACHIEVED
C
      RANGE=RANGE-(4*PER)
      GO TO 9
    8 LESS=.TRUE.
      IUSE2=FFE(N)
      RANGE=RANGE+(4*PER)
C
C     THE FOLLOWING REFERS TO DEFLECTION CORRECTION.
C   DEFLECTION IS CORRECT WHEN HALF-S BRACKET IS SPLIT.
C
    9 HALFS=2*RN/1000
      CHECK=ABS(DEFLEC)
      IF(CHECK.LT.HALFS.AND.N.GT.1)GO TO 93
C
C     IF NOT WITHIN HALF-S, CONTINUE TO CONSIDER DEFLECTION.
C
      WIDFFE(N)=(RAN(0))*PED/.6745+DEFLEC
      IF(WIDFFE(N).LT.0)GO TO 92
      DEFLEC=DEFLEC-HALFS
      GO TO 91
   92 DEFLEC=DEFLEC+HALFS
      GO TO 91
   93 K=N
   91 N=N+1
      FFE(N)=(RAN(0))*PER/.6745+RANGE
      IF(FFE(N).LT.0.0.AND.LESS.OR.FFE(N).GT.0.0.AND..NOT.LE
     ASS) GO TO 7
      IF(FFE(N).LT.0.0)GO TO 10
C
C     AFTER A FORK BRACKET IS ESTABLISHED, SHIFT 2 PER.
C
      IUSE1=FFE(N)
      RANGE=RANGE-(2*PER)
      GO TO 11
   10 IUSE2=FFE(N)
      RANGE=RANGE+(2*PER)
C
C     THE FOLLOWING ROUNDS WILL BE USED IN COMPUTING THE AD-
C   JUSTED ELEVATION.  THEIR LOCATION WILL BE RECORDED BOTH
C   AS ESTIMATED BY THE PROCEDURE AND AS GENERATED BY THE
C   MODEL.
C
   11 CENTER=RANGE
  999 I=I+1
      N=N+1
      FFE(N)=(RAN(0))*PER/.6745+RANGE
C
C     IF DEFLECTION IS STILL NOT CORRECT, CONTINUE TO
C   COMPUTE IT.
C
      IF (K.GT.0) GO TO 94
      WIDFFE(N)=RAN(0)*PED/.6745+DEFLEC
      IF (WIDFFE(N).LT.0)GO TO 95
      DEFLEC=DEFLEC-HALFS
      GO TO 96
```

```
C     THIS SUBROUTINE  MODELS THE ALTERNATE PRECISION
C   REGISTRATION PROCEDURES, BOTH FOR 6 AND 10 ROUNDS.  IT IS
C   CAPABLE OF EMPLOYING ANY NUMBER OF ROUNDS.


      SUBROUTINE NEW
      REAL MISDIS
      INTEGER Z,Z2,SENSE,DSENSE,SUM,DSUM,FORGET,DROP,CHANGE
      COMMON RN,PER,FIRST,IADD,MISDIS,DISP,Z,AWAY,STDDEV,Z2,
     AAWAY2,STDV2,DIST,FERST,PED,STDDV,NROUND
      DIMENSION SENSE(40),STRIKE(40),FORGET(40),IOUT(40),DST
     ARIK(40),DSENSE(40),RADIAL(40),DROP(40)
C
C     INITIALIZE VALUES OF COUNTERS, SUMS,ETC.
C
      N=1
      KCUNT=0
      Z=0
      Z2=0
      SUM=0
      DSUM=0
C
C     ZERO ALL ARRAYS
C
      DO 103 I=1,40
      SENSE(I)=0
      STRIKE(I)=0
      FORGET(I)=0
      DSTRIK(I)=0
      DSENSE(I)=0
      RADIAL(I)=0
  103 IOUT(I)=0
C
C     USE FIRST ROUND LOCATION AS DETERMINED IN MAIN PROGRAM
C
      STRIKE(N)=FIRST
      DSTRIK(N)=FERST
C
C     PROCEDURALY THE FO MAKES A RANGE AND DEFLECTION SENS-
C   ING.  HE MAKES AN ERROR IN BOTH SENSINGS ACCORDING TO THE
C   ERROR FUNCTION ESTABLISHED IN SUBROUTINE "ERFCN".
C
    1 SENSE(N)=ERRFCN(DIST,STRIKE(N))
      DSENSE(N)=ERRFCN(DIST,DSTRIK(N))
C
C     THE COMPUTER DETERMINES THE RADIAL MISS DISTANCE.
C
      TEST=DSENSE(N)**2+SENSE(N)**2
      RADIAL(N)=SQRT(TEST)
      M=N
C
C     COMPUTER DETERMINES THE MEAN OF ALL SENSINGS.
C
  101 SMEAN=FLOAT(SUM+SENSE(N))/N
      DMEAN=FLOAT(DSUM+DSENSE(N))/N
C
C     COMPUTE SHIFT REQUIRED TO PUT COMPUTED CI OVER THE
C   REGISTRATION POINT.
C
      SHIFT=-SMEAN
      DSHIFT=-DMEAN
C
C     UPDATE ALL PREVIOUS ROUND LOCATIONS BASED ON LATEST
C   ESTIMATE OF THE MEAN OF THE ROUNDS FIRED
C
      SUM=0
      TOTAL=0
C
C     PARALLEL RECORDS ARE MAINTAINED THROUGHOUT ON THE
C   LOCATION OF BURSTS ESTIMATED BY THE PROCEDURE AND THOSE
C   ACTUALLY GENERATED.  THUS EVERY COMPUTATION IS DONE FOR
C   BOTH SETS OF DATA.
```

```
   95 DEFLEC=DEFLEC+HALFS
   96 CHECK=ABS(DEFLEC)
      IF(CHECK.GT.HALFS)GO TO 94
      K=N
   94 IF(FFE(N).LT.0)GO TO 12
      OVER=OVER+1
      GO TO 13
   12 SHORT=SHORT+1
   13 IUSE(I)=FFE(N)
C
C       IF THREE ROUNDS HAVE BEEN FIRED AT THE CENTER ELEVATION
C     THE PREPONDERANCE IS COMPUTED AND A SHIFT OF 2 PER MADE
C     AWAY FROM THAT PREPONDERANCE.  A TOTAL OF SIX ROUNDS, TWO
C     PER APART ARE USED IN THE FINAL COMPUTATION OF ADJUSTED
C     ELEVATION.
C
      IF(I.EQ.3.OR.I.EQ.6)GO TO 14
      GO TO 999
   14 IF(I.EQ.6)GO TO 17
      I=I+1
C
C     DETERMINE PREPONDARANCE.
C
      IF(OVER.GT.SHORT)GO TO 15
      RANGE=RANGE+(2*PER)
      IUSE(I)=IUSE1
      OVER=OVER+1
      GO TO 16
   15 RANGE=RANGE-(2*PER)
      IUSE(I)=IUSE2
      SHORT=SHORT+1
   16 OTHER=RANGE
      GO TO 999
C
C       FIRING OF REGISTRATION IS COMPLETE.  ADJUSTED ELEVA-
C     TION AND DEFLECTION ARE NOW COMPUTED  USING A PREPONDER-
C     ANCE FORMULA.
C
   17 CORR=(SHORT-OVER)*PER*2/(SHORT+OVER)
      ADJCI=((CENTER+OTHER)/2)+CORR
C
C       MISS DISTANCE IN RANGE AND DEFLECTION IS COMPUTED, AND
C     CONVERTED TO RADIAL MISS DISTANCE
C
      MISDIS=SQRT(ADJCI**2+CHECK**2)
C
C       THE STANDARD DEVIATIONS IN RANGE AND DEFLECTIONS WERE
C     COMPUTED FOR THE ROUNDS USED IN DETERMINING THE ADJUSTED
C     ELEVATION AND DEFLECTION.  THIS INFORMATION WAS FOR VAL-
C     IDATION PURPOSES ONLY AND DID NOT PLAY A PART IN THE
C     FINAL RESULTS PRESENTED IN THE THESIS.
C
      SUM=0.0
      SQMEAN=0.0
      DO 18 K=1,I
      SUM=SUM+IUSE(K)
   18 SQMEAN=SQMEAN+IUSE(K)**2
      AVRG=SUM/I
      DISP=SQRT((SQMEAN/I)-AVRG**2)
      IADD=J+N
      TOT=0
      SQUARE=0
      DO 20 I=1,J
      TOT=TOT+WIDE(I)
   20 SQUARE=SQUARE+WIDE(I)**2
      DO 21 I=1,K
      TOT=TOT+WIDFFE(I)
   21 SQUARE=SQUARE+WIDFFE(I)**2
      AVG=TOT/(J+K)
      STDDV=SQRT((SQUARE/(J+K)-AVG**2))
      RETURN
      END
```

```
C
      DSUM=0
      DTOTAL=0
      DO 2 I=1,N
      DSENSE(I)=DSENSE(I)+DSHIFT
      DSTRIK(I)=DSTRIK(I)+DSHIFT
      SENSE(I)=SENSE(I)+SHIFT
    2 STRIKE(I)=STRIKE(I)+SHIFT
C
C     IF SPECIFIED NUMBER OF ROUNDS HAVE BEEN FIRED
C   (NROUND), THE FIRING IS STOPPED.
C
      IF (N.EQ.NROUND) GO TO 20
      N=N+1
C
C     THE FALL OF SHOT IN RANGE AND DEFLECTION IS SIMULATED
C   IN THE FOLLOWING STATEMENTS JUST AS IT WAS DONE IN THE
C   SUBROUTINE"CLD".
C
      STRIKE(N)=(RAN(0)*PER/.6745+SMEAN)
      DSTRIK(N)=RAN(0)*PED/.6745+DMEAN
      GO TO 1
   20 CONTINUE
C
C     COMPUTE ERROR (MISS DISTANCE) BY COMPARING THE CI
C   ESTIMATED BY THE PROCEDURE WHITH THAT COMPUTED FROM THE
C   DATA ON THE ROUNDS AS ACTUALLY FIRED.
      DO 11 I=1,N
      DSUM=DSUM+DSENSE(I)
      DTOTAL=DTOTAL+DSTRIK(I)
      SUM=SUM+SENSE(I)
   11 TOTAL=TOTAL+STRIKE(I)
      AWRY=TOTAL/M
      DAWRY=DTOTAL/M
      AWAY=SQRT(AWRY**2+DAWRY**2)
C
C     THE FOLLOWING COMPUTATION OF STANDARD DEVIATIONS IN
C   RANGE AND DEFLECTION WAS NOT INCLUDED IN FINAL THESIS
C   RESULTS.
C
    4 SQMEAN=0
      DO 5 K=1,N
    5 SQMEAN=SQMEAN+(STRIKE(K))**2
      STDDEV=SQRT((SQMEAN/M)-(AWRY**2))
      TOT=0
      SQUARE=0
      DO 21 I=1,N
      TOT=TOT+DSTRIK(I)
   21 SQUARE=SQUARE+DSTRIK(I)**2
      STDDV=SQRT((SQUARE/N)-(TOT/N)**2)
      MISDIS=AWAY
      DISP=STDDEV
      IADD=N
      RETURN
      END
```

```
C
C      THIS SUBROUTINE IS TAKEN DIRECTLY FROM THE IBM
C  LIBRARY OF SUBROUTINES.
C
C      THE SIMULATION MODEL USED WITH THIS THESIS USED ONLY
C  OPTION 4.
C      ..............................................................
C         SUBROUTINE TTEST
C      ..............................................................
C
C

      SUBROUTINE TTEST (A,NA,B,NB,NOP,NDF,ANS)
C
C
C         SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C            NONE
      DIMENSION A(1),B(1)
C
C      INITIALIZATION
C
      NDF=0
      ANS=0.0
C
C      CALCULATE THE MEAN OF A
C
      AMEAN=0.0
      DO 110 I=1,NA
  110 AMEAN=AMEAN+A(I)
      FNA=NA
      AMEAN=AMEAN/FNA
C
C      CALCULATE THE MEAN OF B
C
  115 BMEAN=0.0
      DO 120 I=1,NB
  120 BMEAN=BMEAN+B(I)
      FNB=NB
      BMEAN=BMEAN/FNB
C
      IF(NOP-4) 122, 125, 200
  122 IF(NOP-1) 200, 135, 125
C
C      CALCULATE THE VARIANCE OF A
C
  125 SA2=0.0
      DO 130 I=1,NA
  130 SA2=SA2+(A(I)-AMEAN)**2
      SA2=SA2/(FNA-1.0)
C      STANDARD DEVIATION OF A
C
      SDA=SQRT(SA2)
C
C      CALCULATE THE VARIANCE OF B
C
  135 SB2=0.0
      DO 140 I=1,NB
  140 SB2=SB2+(B(I)-BMEAN)**2
      SB2=SB2/(FNB-1.0)
C
C      STANDARD DEVIATION OF B
      SDB=SQRT(SB2)
C
      GO TO (150,160,170,180), NOP
C
C         OPTION 1
```

```
C
  150 ANS=((BMEAN-AMEAN)/SQRT(SB2))*SQRT(FNB)
      NDF=NB-1
      GO TO 200
C
C         OPTION 2
C
  160 NDF=NA+NB-2
      FNDF=NDF
      S=SQRT(((FNA-1.0)*SA2+(FNB-1.0)*SB2)/FNDF)
      ANS=((BMEAN-AMEAN)/S)*(1.0/SQRT(1.0/FNA+1.0/FNB))
      GO TO 200
C
C         OPTION 3
C
  170 ANS=(BMEAN-AMEAN)/SQRT(SA2/FNA+SB2/FNB)
      A1=(SA2/FNA+SB2/FNB)**2
      A2=(SA2/FNA)**2/(FNA+1.0)+(SB2/FNB)**2/(FNB+1.0)
      NDF=A1/A2-2.0+0.5
      GO TO 200
C
C         OPTION 4
C
  180 SD=0.0
      D=BMEAN-AMEAN
      DO 190 I=1,NB
  190 SD=SD+(B(I)-A(I)-D)**2
      SDBAR=SQRT(SD/((FNB-1.0)*FNB))
      ANS=D/SDBAR
      NDF=NB-1
C
  200 RETURN
      END
```

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13. ABSTRACT

This thesis is addressed to the problem of selecting a precision registration procedure for the Field Artillery. The author hypothesized that, in view of recently procured automatic data processing equipment, the current procedure is neither the most accurate nor the most economical procedure possible. An alternate procedure was designed and compared with the current procedure through the use of a computer simulation model. Data from the simulation was analyzed and conclusions were drawn regarding the relative accuracy and economy of the two procedures.

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